US007784390B1

(12) **United States Patent**
Lowell et al.

(10) **Patent No.: US 7,784,390 B1**
(45) **Date of Patent: *Aug. 31, 2010**

(54) **SOLID-STATE NON-LETHAL DIRECTED ENERGY WEAPON**

(75) Inventors: **Reid F. Lowell**, Ontario, CA (US); **Kenneth W. Brown**, Yucaipa, CA (US); **A-Lan V. Reynolds**, Tucson, AZ (US); **Alan A. Rattray**, Alta Loma, CA (US)

(73) Assignee: **Raytheon Company**, Waltham, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 467 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **11/867,579**

(22) Filed: **Oct. 4, 2007**

Related U.S. Application Data

(63) Continuation-in-part of application No. 11/207,049, filed on Aug. 18, 2005, now Pat. No. 7,490,538.

(51) **Int. Cl.**
F41H 13/00 (2006.01)
F41C 27/00 (2006.01)

(52) **U.S. Cl.** **89/1.11**; 42/1.08; 42/84

(58) **Field of Classification Search** 89/1.11; 42/1.08, 84

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,325,305	A	4/1982	Pastine	
5,736,908	A	4/1998	Alexanian	
5,886,664	A *	3/1999	Yujiri et al.	342/351
6,252,558	B1	6/2001	Brown	
6,487,950	B2	12/2002	Samland	
6,559,724	B2	5/2003	Rosenberg et al.	
6,765,535	B1	7/2004	Brown	
6,799,499	B2	10/2004	Seregelyi et al.	
6,843,178	B2	1/2005	Wood et al.	
7,126,477	B2	10/2006	Gallivan et al.	
7,490,538	B2 *	2/2009	Lowell et al.	89/1.11
2007/0040725	A1	2/2007	Lowell	
2007/0139247	A1	6/2007	Brown	

FOREIGN PATENT DOCUMENTS

EP	1396699	3/2004
WO	WO 2007/022339	2/2007

OTHER PUBLICATIONS

Raytheon, Silent Guardian, Jun. 2006.

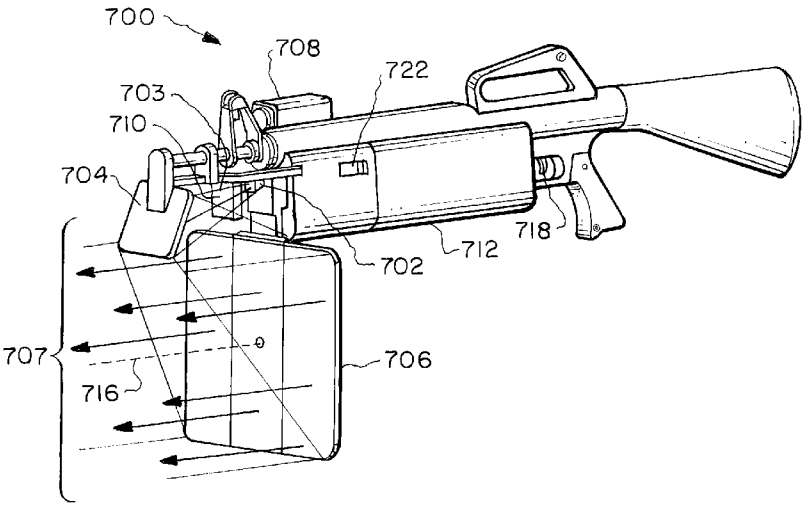
(Continued)

Primary Examiner—Bret Hayes
(74) *Attorney, Agent, or Firm*—SoCal IP Law Group LLP; Steven C. Sereboff; John E. Gunther

(57) **ABSTRACT**

There is disclosed a solid state non-lethal directed energy weapon. The non-lethal weapon may include a solid-state source to generate a high-power millimeter-wave initial wavefront, a main reflector, and a sub-reflector to reflect the initial wavefront to the main reflector. The main reflector may direct the reflected wavefront in a bore-sighted direction toward a target. The wavefront directed by the main reflector may have a power density selected to deliver a non-lethal deterring effect on the target.

19 Claims, 10 Drawing Sheets



OTHER PUBLICATIONS

Wikipedia, Active Denial System, 2007.
Malibu Research, FLAPS Antenna Technology.
Walters et al.,"Heating and pain sensation produced in human skin by millimeter waves: comparison to a simple thermal model," 2000.
Walters et al., "Effects of blood flow on skin heating induced by millimeter wave irradiation in humans," 2004.
Blick et al., "Thresholds of microwave-evoked warmth sensation in human skin," 1997.
Riu et al., "A thermal model for human thresholds of microwave-evoked warmth sensation," 1996.
GlobalSecurity.org, "Vehicle-Mounted Active Denial Technology (V-MADS)," Internet, Archived as shown in box at top of page, Jan. 7, 2003, 6 pages.
International Search Report and Written Opinion in re International Patent Application No. PCT/US2006/032117, Feb. 2007.
Hackett, K. E., et al., "Active Denial Technology," http://www.afrlhorizons.com/Briefs/Sept01/De0101.html>, Internet Article, Retrieved from the Internet Jan. 22, 2007.

* cited by examiner

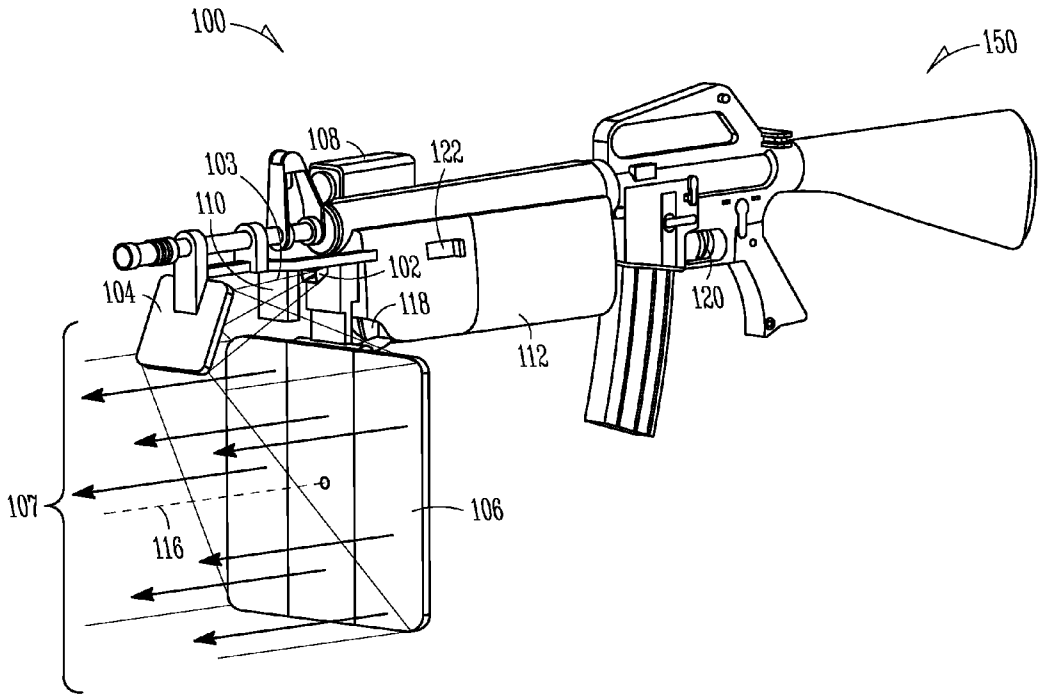

100
150
108
122
103
110
102
104
118
120
112
107
106
116

FIG. 1

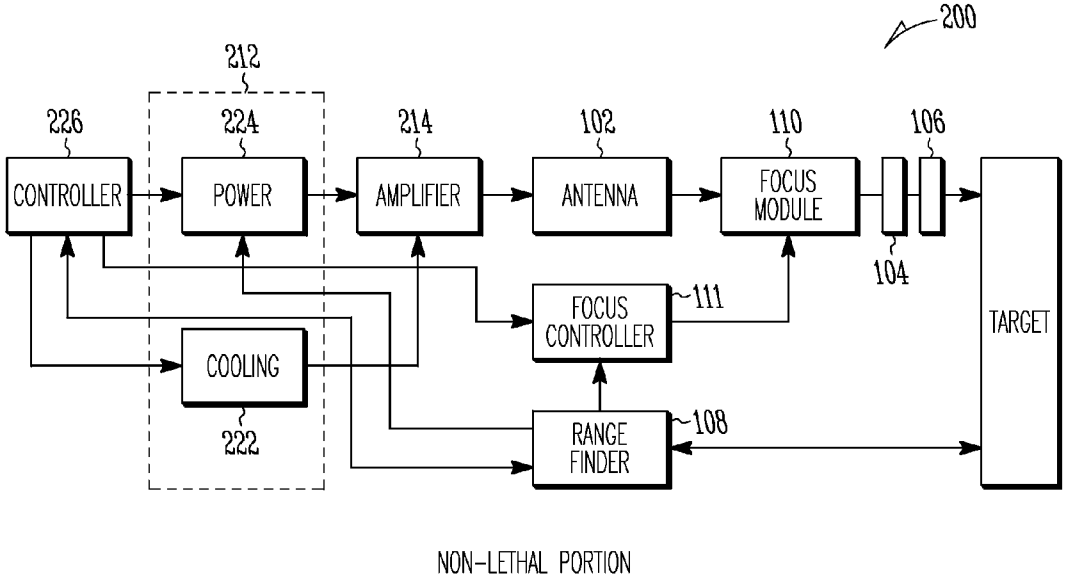

200
212
226
224
214
102
110
106
CONTROLLER
POWER
AMPLIFIER
ANTENNA
FOCUS MODULE
104
FOCUS CONTROLLER
111
TARGET
COOLING
222
RANGE FINDER
108
NON-LETHAL PORTION

FIG. 2

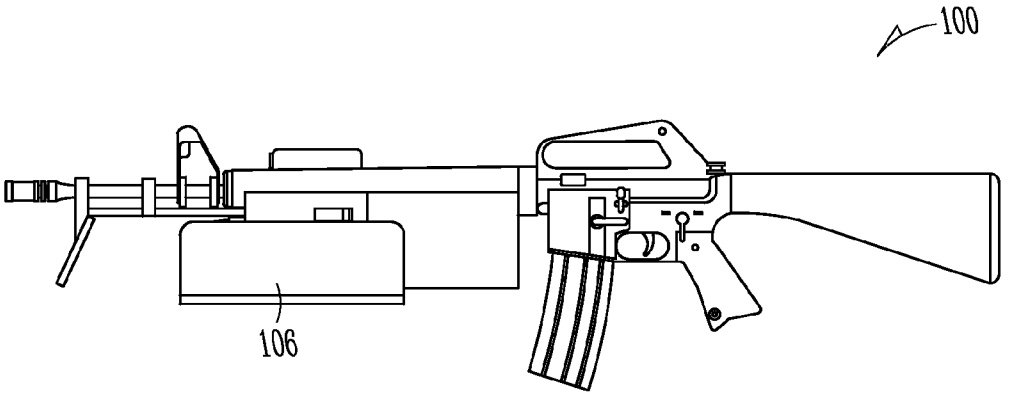


FIG. 3A

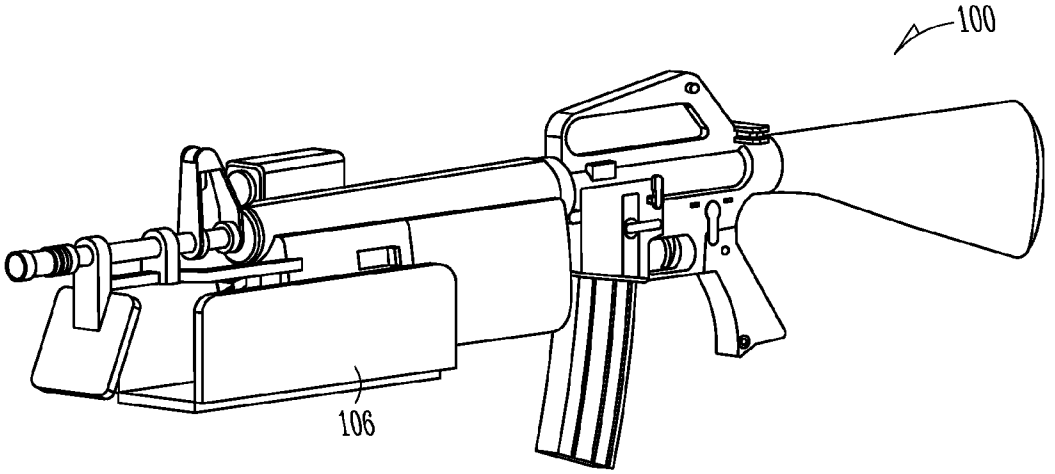


FIG. 3B

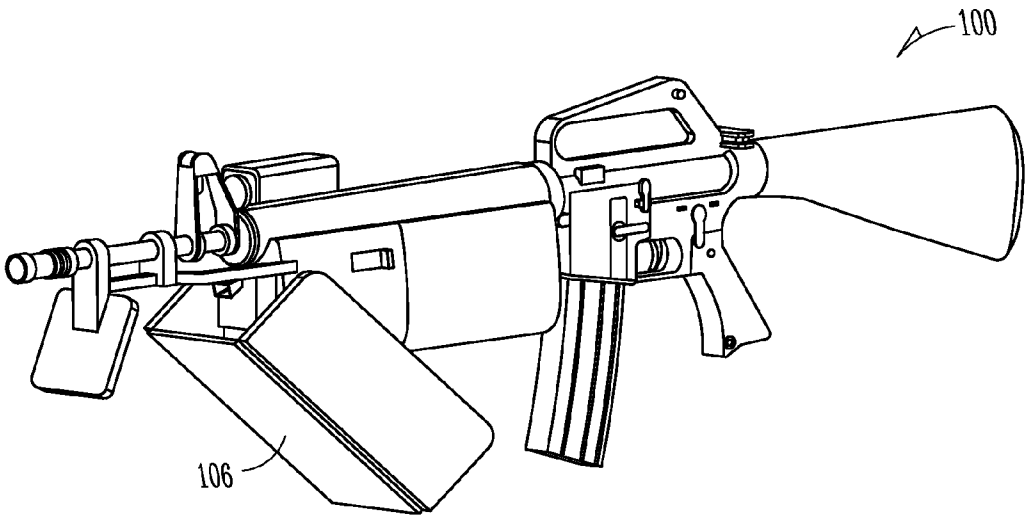


FIG. 3C

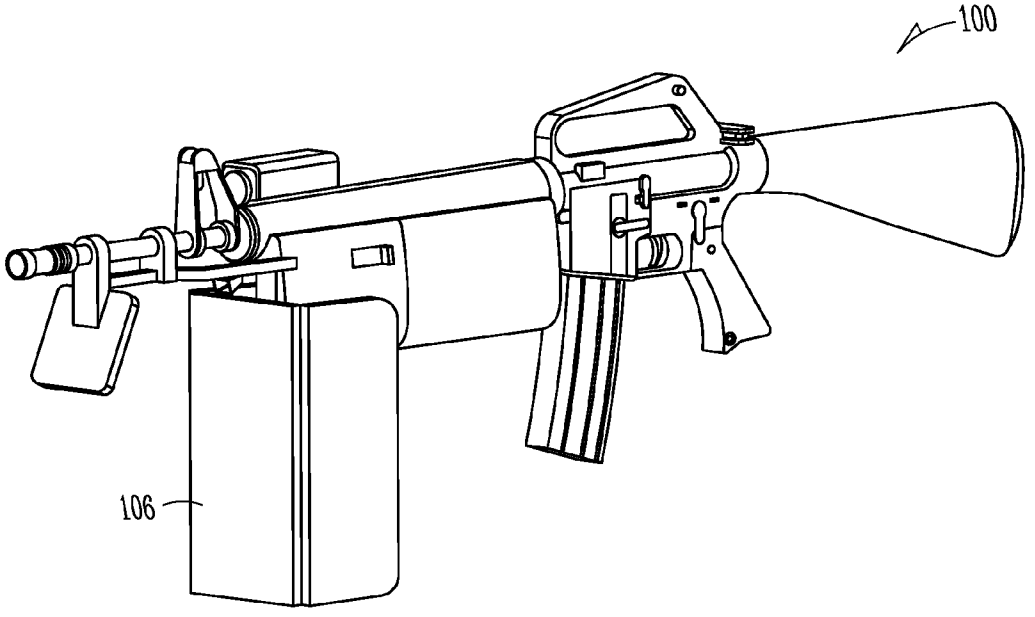


FIG. 3D

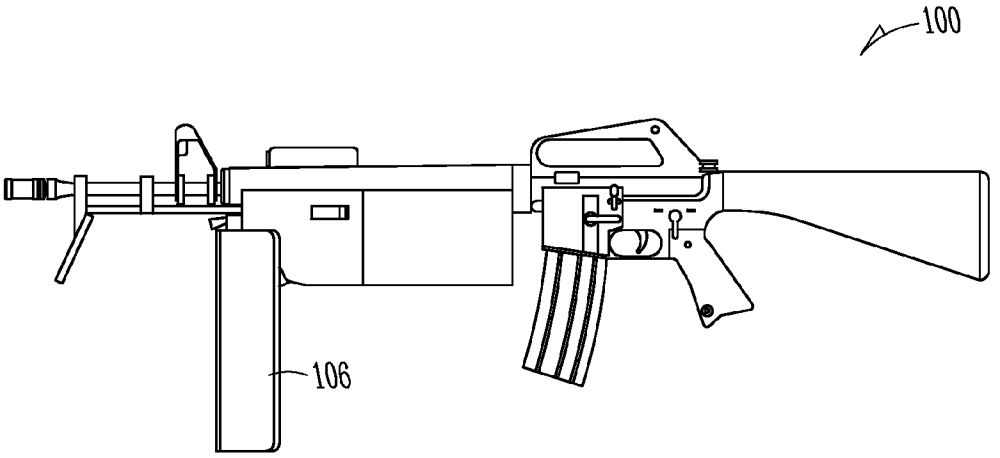


FIG. 3E

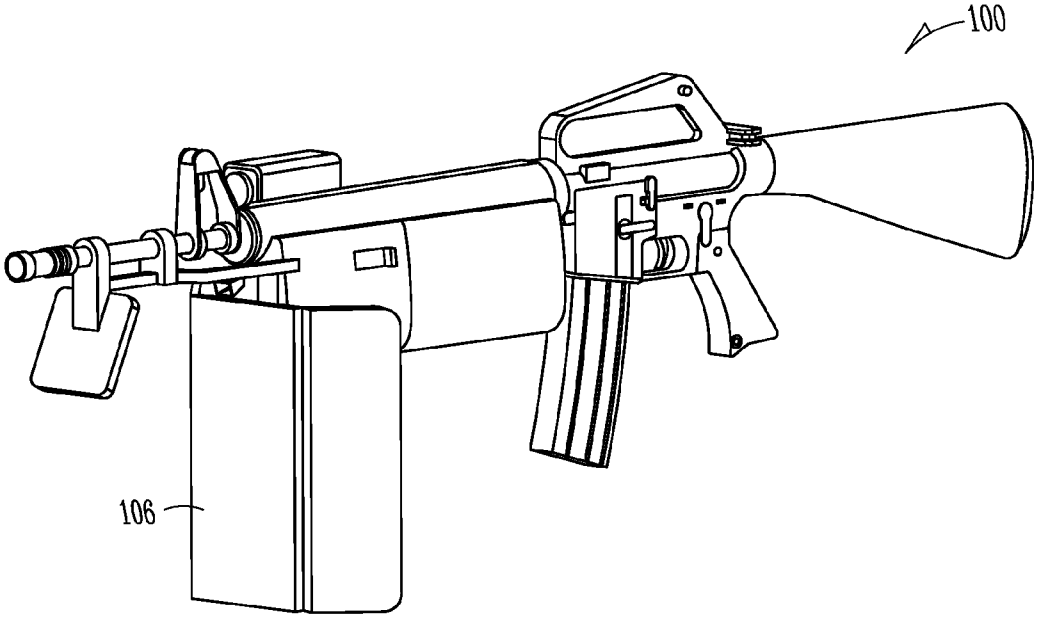


FIG. 3F

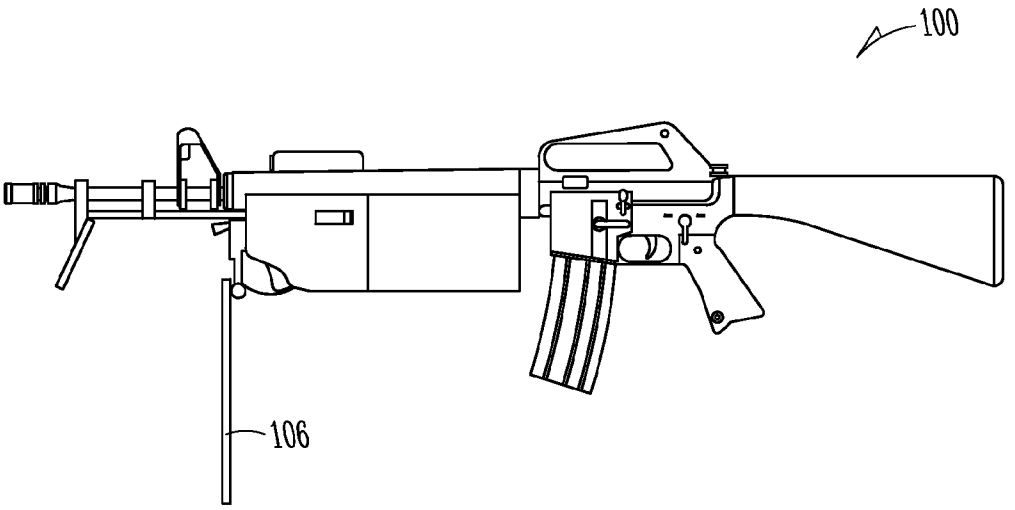


FIG. 4A

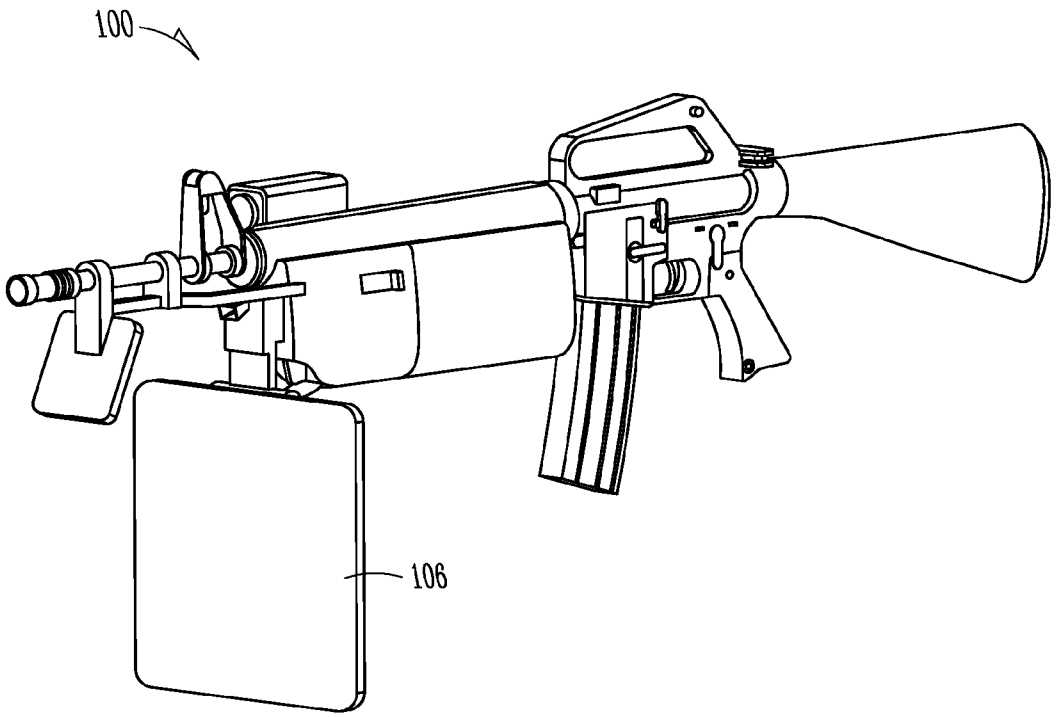


FIG. 4B

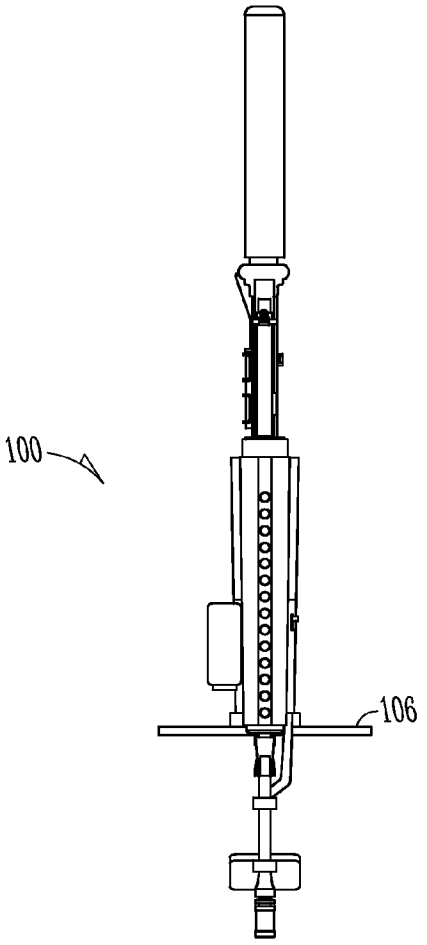


FIG. 4C

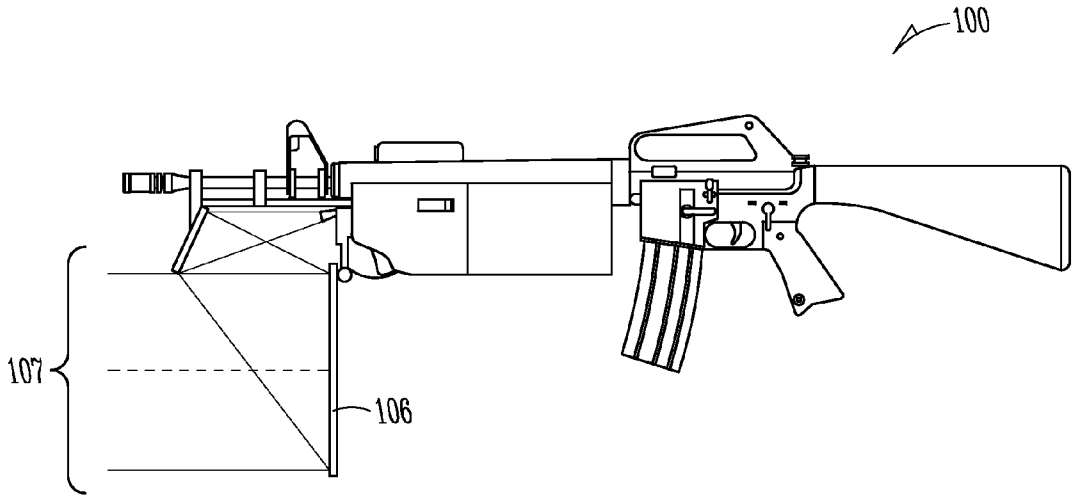


FIG. 5A

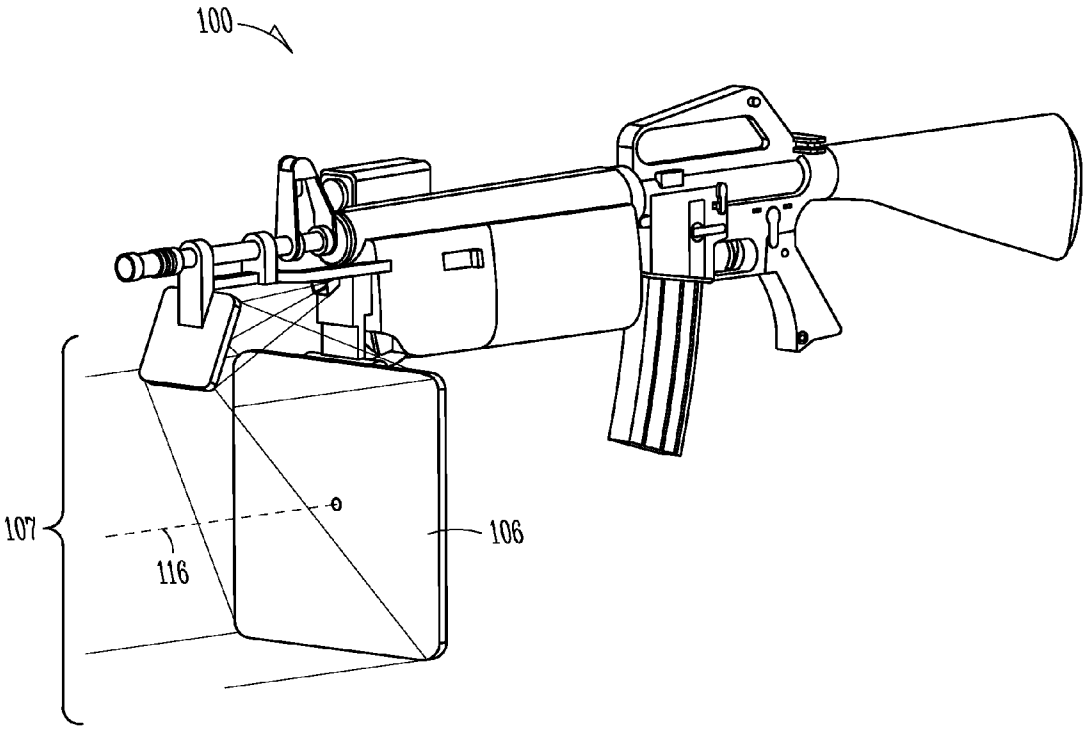


FIG. 5B

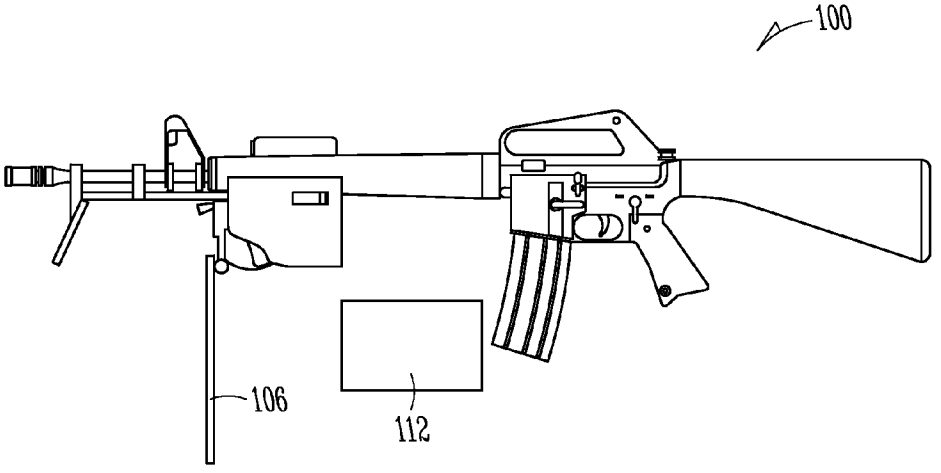


FIG. 6A

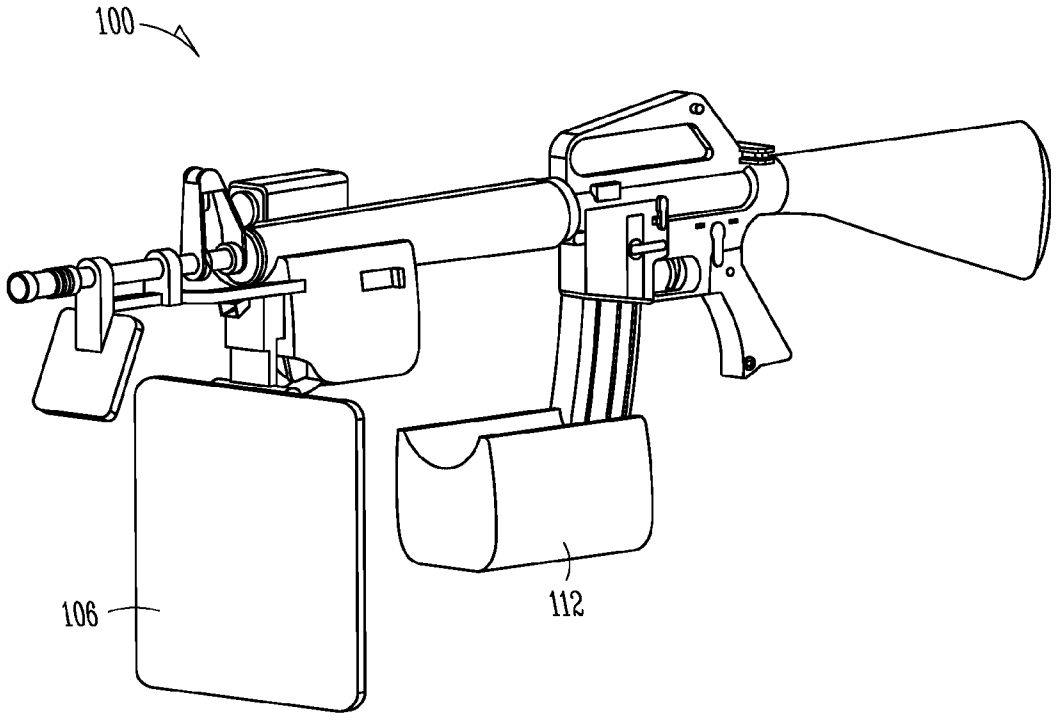


FIG. 6B

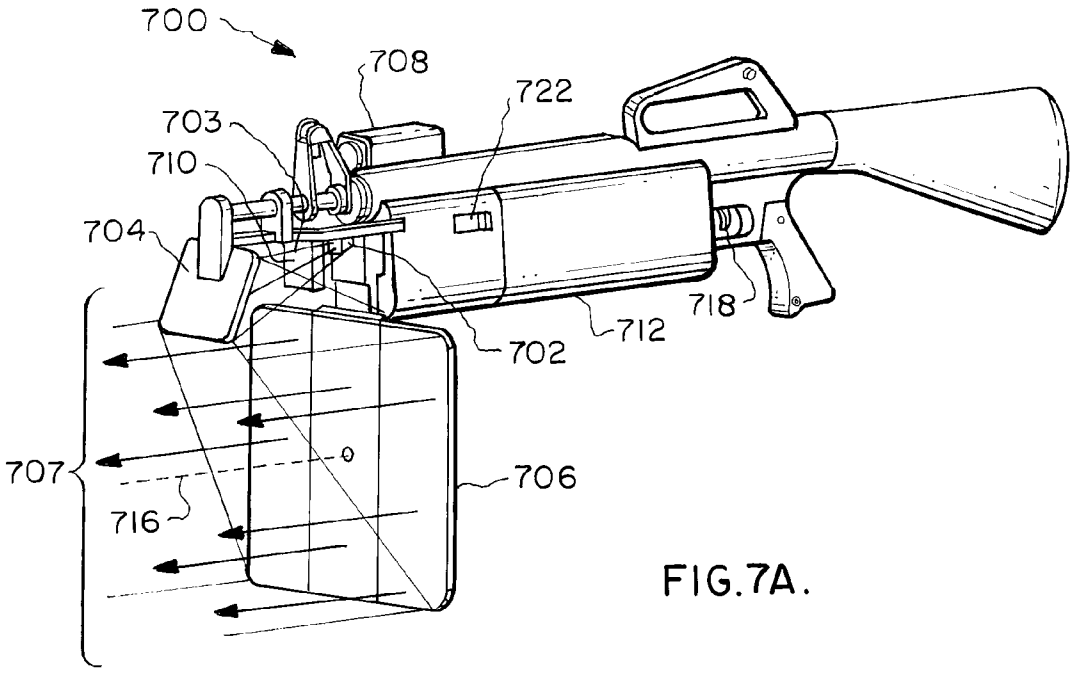


FIG.7A.

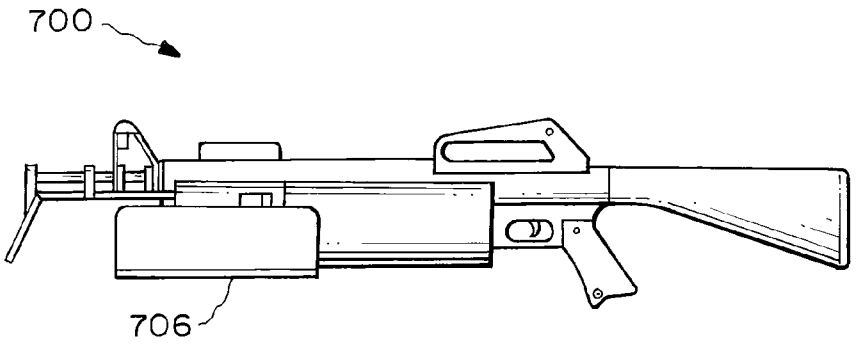


FIG.7B

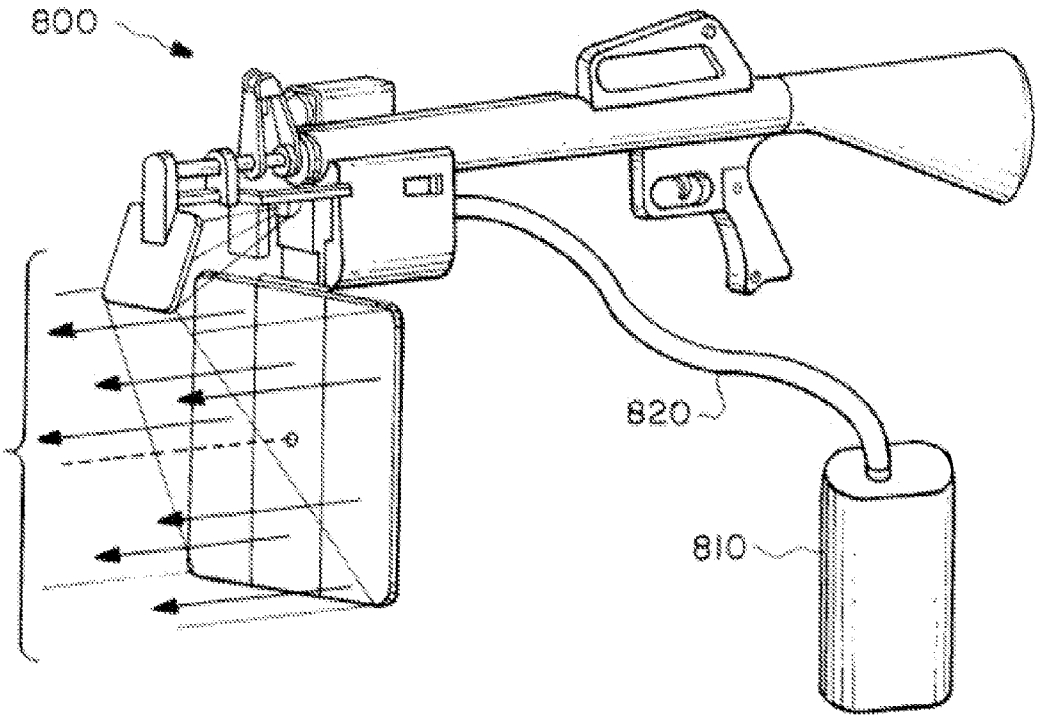


FIG. 8A.

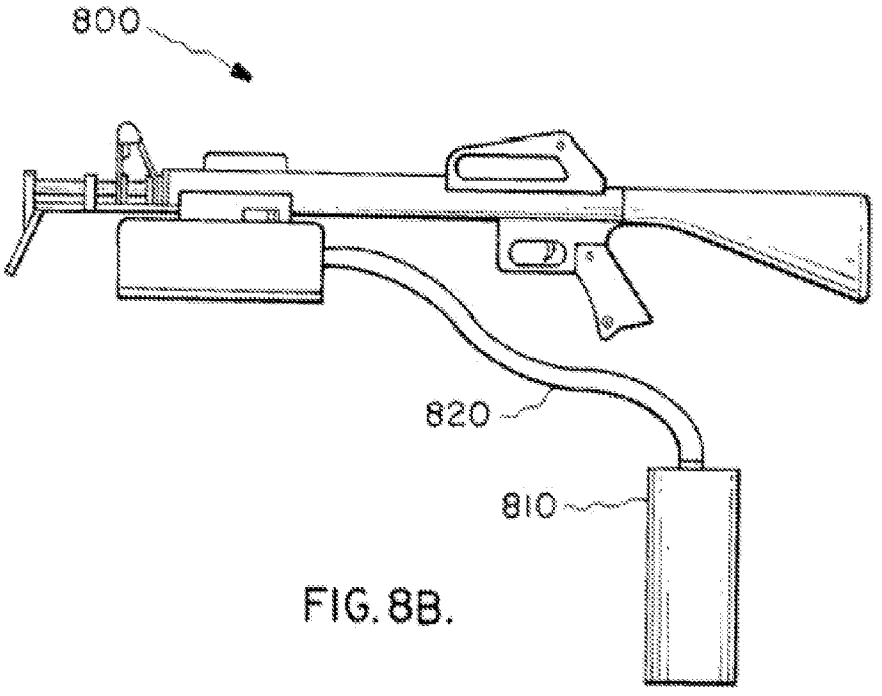


FIG. 8B.

SOLID-STATE NON-LETHAL DIRECTED ENERGY WEAPON

RELATED APPLICATION INFORMATION

This patent is a continuation-in-part of application Ser. No. 11/207,049, "Weapon having lethal and non-lethal directed energy portions", filed Aug. 18, 2005, now U.S. Pat. No. 7,490,538 B2.

BACKGROUND

1. Field

This disclosure relates to non-lethal directed energy weapons.

2. Description of the Related Art

There are many difficult quickly changing situations in modern urban conflicts that security personnel must deal with. In modern urban conflicts, security personnel must execute dynamically changing missions that could shift rapidly between direct action, security patrols and civil stability. Among the mix of unarmed civilians, non-lethal combatants (e.g., rock throwing) and lethal combatants, it is often not immediately clear who is an innocent bystander and who poses an immediate threat to security personnel. Options for security personnel many times progress quickly from shouting to shooting. Modern urban conflicts many times require a delicate balance between the use of non-lethal force and the use of lethal force. Non-lethal weapons, when available, are generally carried separate from lethal weapons resulting in a potentially life-threatening delay for security personnel when switching between the types of weapons. Urban riot situations, for example, can easily escalate in a moment's notice and require security personnel to switch between a non-lethal response and a lethal response.

One problem with many non-lethal weapons is that they are largely ineffective over the range that lethal weapons are effective. For example, a non-lethal kinetic weapon that sends projectiles (e.g., rubber bullets) must have a reasonable range to maintain its nonlethality, however, the weapon becomes potentially lethal at close range when powerful enough to be used for longer ranges due to the initial velocity required to project the projectile over these longer ranges.

Thus, there are general needs for a non-lethal weapon that can easily be deployed. There are also needs for a combined lethal/non-lethal weapon that has an effective non-lethal range comparable to its lethal range. There are also needs for a combined lethal/non-lethal weapon that allows security personnel to easily and quickly switch between non-lethal and lethal capabilities.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a combined lethal and non-lethal weapon.

FIG. **2** is a functional block diagram of the non-lethal portion of the weapon of FIG. **1**.

FIG. **3**A is a side view illustrating the main reflector in a fully folded-up position.

FIG. **3**B is a perspective view illustrating the main reflector in a fully folded-up position.

FIG. **3**C is a perspective view illustrating the main reflector in a partially folded-up position.

FIG. **3**D is a perspective view illustrating wings of the main reflector folded-up.

FIG. **3**E is a side view illustrating wings of the main reflector partially folded-up.

FIG. **3**F is a perspective view illustrating wings of the main reflector partially folded-up.

FIG. **4**A is a side view illustrating the main reflector in a fully-deployed position;

FIG. **4**B is a perspective view illustrating the main reflector in a fully-deployed position.

FIG. **4**C is a top view of the weapon illustrated in FIGS. **4**A and **4**B.

FIG. **5**A is a side view illustrating the operation of the non-lethal portion of a combined lethal and non-lethal weapon.

FIG. **5**B is a perspective view illustrating the operation of the non-lethal portion of a combined lethal and non-lethal weapon.

FIG. **6**A is a side view illustrating a removable energy-storage module.

FIG. **6**B is a perspective view illustrating the removable energy-storage module.

FIG. **7**A is a perspective view of a solid-state non-lethal weapon.

FIG. **7**B is a side view of the solid-state non-lethal weapon of FIG. **8**A illustrating the main reflector in a fully folded-up position.

FIG. **8**A is a perspective view of another solid-state non-lethal weapon.

FIG. **8**B is a side view of the solid-state non-lethal weapon of FIG. **8**A illustrating the main reflector in a fully folded-up position.

DETAILED DESCRIPTION

The following description and the drawings illustrate specific embodiments of the invention sufficiently to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Examples merely typify possible variations. Individual components and functions are optional unless explicitly required, and the sequence of operations may vary. Portions and features of some embodiments may be included in or substituted for those of others. Embodiments of the invention set forth in the claims encompass all available equivalents of those claims. Embodiments of the invention may be referred to, individually or collectively, herein by the term "invention" merely for convenience and without intending to limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed.

A weapon in accordance with some embodiments of the present invention combines lethal capability with non-lethal capability allowing a user to easily switch between lethal and non-lethal force in a moment's notice. In many urban conflict situations, this ability may help save the lives of security personnel as well as the lives of innocent non-combatants. The non-lethal portion uses directed energy which, unlike many other non-lethal weapons (e.g., rubber bullets, taser, water cannons), generally causes no residual damage to a person fired upon. Because energy is the ammunition, the logistical burdens associated with conventional non-lethal weapons are significantly reduced.

FIG. **1** is a perspective view of a weapon in accordance with some embodiments of the present invention. Weapon **100** comprises a non-lethal portion and a lethal portion **150**. The lethal portion **150** may be any lethal weapon including a rifle or machine gun. The non-lethal portion may comprise a directed energy weapon and may be bore-sighted or aligned with the lethal portion. In some embodiments, the non-lethal

portion may be a kit allowing non-lethal capability to be added to a lethal weapon, although the scope of the invention is not limited in this respect.

The non-lethal portion of weapon **100** may comprise an output antenna **102** to transmit a high-power millimeter-wave initial wavefront **103**, a main reflector **106**, and a sub-reflector or sub-reflectors **104** to reflect and shape the initial wavefront **103** to the main reflector **106**. The main reflector **106** may direct wavefront **107** in a bore-sighted direction toward a target.

In some embodiments, non-lethal portion of weapon **100** may also comprise rangefinder **108** to determine a range to the target, focus module **110** to focus wavefront **107**, replaceable energy-storage module **112** to provide energy to the non-lethal portion, and laser designator **116** for designating the target. In some embodiments, non-lethal portion may also include trigger **118** to cause the generation of wavefront **107** and on-off switch **122**. These elements are discussed in more detail below.

In some embodiments, wavefront **107** may comprise a millimeter-wave frequency, such as a W-band frequency between 94 and 96 GHz, although the scope of the invention is not limited in this respect. In some embodiments, wavefront **107** directed by main reflector **106** may have a power density selected to deliver a non-lethal deterring effect on the target. In some embodiments, wavefront **107** comprises a frequency selected to penetrate a shallow skin-depth (i.e., of less than five millimeters). In some embodiments, a power density of wavefront **107** at the target may be calculated and selected to cause a deterring effect by inducing pain on human skin. In some embodiments, wavefront **107** may comprise W-band millimeter-wave or higher frequency radiation selected to penetrate only a shallow skin-depth allowing the energy to heat the region of the skin's pain sensors, although the scope of the invention is not limited in this respect.

In some embodiments, main reflector **106** may be a collimating reflector to generate a collimated wavefront toward the target. The collimated wavefront may be substantially uniform in amplitude and/or substantially coherent in phase in a planar cross-section of a column of energy emanating from main reflector **106**, although the scope the invention is not limited in this respect.

In some other embodiments, main reflector **106** may generate a converting wavefront which may converge at or near an intended target. In these embodiments, a convergence distance may be selected to provide a predetermined power density at or near a surface of the target. In some embodiments, main reflector **106** may generate a slightly diverging wavefront. In some embodiments, the focus of wavefront **107** (i.e., whether wavefront **107** is converging, collimated or diverging) may be at least partially controlled by focus module **110**.

In some embodiments, main reflector **106** may be aligned with sights of lethal portion **150** of weapon **100**. In some embodiments, the non-lethal portion may be a bore-sighted attachment kit to add non-lethal capability to a lethal weapon. The kit may be a "B-kit" add-on to a rifle, such as an M-16 rifle, although the scope of the invention is not limited in this respect.

FIG. **2** is a functional block diagram of the non-lethal portion of the weapon of FIG. **1** in accordance with some embodiments of the present invention. Elements illustrated in FIG. **2** having the same reference number as elements in FIG. **1** may refer to the same element. As illustrated in FIG. **2**, non-lethal portion **200** may include system controller **226** to control the operation of the various elements of non-lethal portion **200**. Rangefinder **108** may determine a distance to the target and system controller **226** may determine the proper power density of wavefront **107** at or near the target based on the distance. System controller **226** may control the RF power output of amplifier **214** accordingly. On-off switch **122** may allow power to be turned off to the active elements of the non-lethal portion.

Referring to FIGS. **1** and **2** together, in some embodiments, laser designator **116** may be used to visually designate the target. Laser designator **116** may be bore-sighted with both the lethal portion and non-lethal portion. In some embodiments, rangefinder **108** may be aligned with laser designator **116**. In some embodiments, rangefinder **108** comprises a laser-rangefinder, although the scope of the invention is not limited in this respect.

In some embodiments, laser designator **116** may generate a laser-beam in parallel to wavefront **107** and may comprise a laser-diode mounted on main reflector **106**. In some embodiments, laser designator **116** may shine through a small hole in main reflector **106**. In some alternate embodiments, a laser diode may be provided at or near output antenna **102** and a laser-beam may be reflected by optically reflective portions on reflectors **104** and **106** and may be provided parallel to wavefront **107**.

Focus module **110** may change a focus of initial wavefront **103** generated by output antenna **102** based on a distance to the target. This may allow the power-density of wavefront **107** to be adjusted based on the distance to the target. In some embodiments, focus module **110** may be moveable by a user allowing the user to select a position for a focusing element based on the distance to the target. In some embodiments, the focusing element may be manually slidable by a user.

In some embodiments, focus module **110** comprises a millimeter-wave radio-frequency (RF) lens that may be positioned by focus controller **111** based on a distance to a target. In some embodiments, focus module **110** may include one or more RF lenses that may be switched in and out of the RF path by focus controller **111** to focus wavefront **107**. In some embodiments, focus controller **111** may change the relative position of sub-reflector **104** to focus wavefront **107**, in which case sub-reflector **104** and focus module **110** may be the same element. In some other embodiments, system controller **226** may change the phasing of electronic phase shifters within main reflector **106** to change the focusing and phase distribution of wavefront **107**.

In yet some other embodiments, focus module **110**, output antenna **102** and amplifier **214** may be combined in an active lens-array in which a plurality of active array elements receive the wavefront, amplify the wavefront, and retransmit the wavefront. The active array elements may include electronic phase shifters to change the focusing and phase distribution of initial wavefront **103**, which will cause a corresponding change in the focus of wavefront **107**.

In some embodiments, focus module **110** may provide a continually variable focusing distance, while in other embodiments; focus module **110** may provide selectable discrete focusing steps. In some embodiments, focus controller **111** and/or system controller **226** may configure main reflector **104**, sub-reflector **104** and/or focus module **110** to generate a collimated wavefront, while in other embodiments; focus controller **111** and/or system controller **226** may configure main reflector **106**, sub-reflector **104** and/or focus module **110** to generate a converting wavefront. In some other embodiments, focus controller **111** and/or system controller **226** may configure main reflector **104**, sub-reflector **104** and/or focus module **110** to generate a slightly diverging wavefront.

In some embodiments, rangefinder **108** and/or focus module **110** are optional. In these embodiments, the focus of the non-lethal portion may be set at a predetermined distance or at infinity. In these embodiments, the power output of amplifier **214** may be varied, although the power output may also be set to a predetermined level.

In some embodiments, focus controller **111** may change a focus of focus module **110** in response to changes in a distance to the target provided by rangefinder **108**. In some of these embodiments, a convergence point of wavefront **107** may be selected by system controller **226** to generate a predetermined power density at or near a target.

In some embodiments, amplifier **214** may be high-power millimeter-wave amplifier coupled to output antenna **102** to generate a high-power RF signal. In some embodiments, amplifier **214** may comprise a solid-state millimeter-wave amplifier comprising a plurality of either Silicon (Si), Gallium-Arsenide (GaAs), Indium Phosphide (InP), Gallium Nitride (GaN) or other semiconductor amplifier elements. Amplifier **214** may be comprised of an array of solid-state semiconductor amplifiers, each of which is coupled to a corresponding antenna in an array of antenna elements. The wavefronts radiated from the array of antenna elements may be spatially combined to form the initial wavefront **103**. In this case, output antenna **102** may be the distributed across the amplifier array and may not exist as a discrete element.

In some embodiments, output antenna **102** may be a horn antenna and initial wavefront **103** may be a substantially spherical wavefront. In some embodiments, initial wavefront **103** may be a substantially planer wavefront spatially combined from wavefronts radiated by an array of antenna elements driven by a corresponding array of solid state amplifier devices.

Replaceable and removable energy-storage module **212** may provide electrical energy for the millimeter-wave amplifier **214** and/or other elements of the non-lethal portion. In some embodiments, energy-storage module **212** comprises power element **224** which may include, for example, either batteries or a fuel cell. In some embodiments, energy-storage module **212** may comprise a disposable battery or power pack, although the scope of the invention is not limited in this respect.

In some embodiments, weapon **100** may further comprise cooling element **222** to cool amplifier **214**. In some embodiments, cooling element **222** may be part of replaceable energy-storage module **212**, although the scope of the invention is not limited in this respect.

In some embodiments, cooling element **222** may circulate a fluid coolant to cool amplifier **214**. In some embodiments, the coolant may comprise a liquid or gas that is simply expended as the weapon is discharged, and cooling element **222** may include a reservoir to store the liquid. In some embodiments, cooling element **222** may use an expanding gas to cool the amplifier **214**. In these embodiments, cooling element **222** may include a pressurized reservoir to store the gas. In some embodiments, the gas may comprise carbon-dioxide (CO2), although the scope of the invention is not limited in this respect. In the embodiments including a coolant reservoir, the reservoir may be recharged by refilling the reservoir with the appropriate material.

In some embodiment, cooling element **222** may circulate a fluid to transfer heat from the amplifier **214** to a heat-storage reservoir, which may be filled with a phase change material. The phase change material may be an inorganic or organic material, for example a wax, that is capable of absorbing a large quantity of heat while changing from a solid phase to a liquid phase, or from a liquid phase to a gas phase. In the embodiments including a heat-storage reservoir, the reservoir may be recharged by cooling the reservoir sufficiently to reverse the phase change such that the phase change material reverts to its original solid or liquid phase.

In the embodiments using a coolant reservoir or a heat storage reservoir, the reservoir, including the material therein, may be replaceable. The reservoir may be integrated with and replaced with energy-storage module **212**. In these embodiments, the reservoir may be recharged at the same time that the energy-storage module is recharged.

In some other embodiments, cooling element **222** may comprise a semiconductor-based thermo-electric cooling (TEC) element to remove heat from amplifier **214** using electric current, although the scope of the invention is not limited in this respect.

Although FIG. **2** illustrates replaceable module **212** as including power element **224** and cooling element **222**, the scope of the invention is not limited in this respect. In some embodiments, replaceable module may also include other elements of non-lethal portion **200**.

Although non-lethal portion **200** is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements, such as system controller **226** (FIG. **2**) and or focus controller **111** (FIG. **2**) may comprise one or more microprocessors, DSPs, application specific integrated circuits (ASICs), and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements of non-lethal portion **200** (FIG. **2**) may refer to one or more processes operating on one or more processing elements.

In some embodiments, weapon **100** may further comprise lethal-weapon trigger **120** to fire the lethal portion of the weapon and non-lethal-weapon trigger **118** to fire the non-lethal portion by generating wavefront **107**.

In accordance with some embodiments, non-lethal portion may operate as follows. Switch **122** may be turned on providing power to amplifier **214** and other elements of non-lethal portion and allowing range-finder **108** to determine a distance to a target. Laser-designator **116** may also be activated to designate the target to the user, however in some embodiments; laser-designator **116** may part of lethal portion **150** and may operate independent of the non-lethal portion. Focus module **110** may adjust the power output of amplifier **214** and/or may focus the various elements based on the target's distance. In some embodiments, the power output and focus may be adjusted based on a distance to the target to provide a predetermined power density (i.e., spot size) at the target. When trigger **118** is pulled, wavefront **107** is generated to deter the target. If use of non-lethal force is not successful, the user may easily switch to lethal force.

In some embodiments, lethal portion **150** comprises a machine gun; however, lethal portion **150** of weapon **100** may comprise almost any type of gun including hand-held guns. In some embodiments, the lethal portion may comprise a rifle or a machine gun, such as an M-16 rifle, although the scope of the invention is not limited in this respect.

In some embodiments, sub-reflector **104** may have a substantially flat millimeter-wave reflective surface. In some other embodiments, sub-reflector **104** has a millimeter-wave reflective surface comprising at least a portion of a substantially hyperboloidal, ellipsoidal or paraboloidal surface. Other specifically tailored reflective surfaces or lenses may also be used.

In some embodiments, main reflector **106** may comprise a geometrically-flat electrically-parabolic surface reflector antenna having a plurality of antenna elements to receive and retransmit an incident wavefront, although the scope of the invention is not limited in this respect. In these embodiments, the antenna elements may have circumferentially varying sizes and may be arranged around a center of the main reflector. In some embodiments, the antenna elements may have their electrical shapes optimized to generate either a collimating or converging wavefront of desired power densities. In some embodiments, the antenna elements may comprise a plurality of dual-polarized dipoles that circumferentially vary in size, although the scope of the invention is not limited in this respect. In some embodiments, the antenna elements may each provide approximately a 0 to 360 degree phase shift, although the scope of the invention is not limited in this respect. In some embodiments, the individual antenna elements may have varying sizes and shapes to receive the wavefront reflected by sub-reflector **104** and generate output wavefront **107** as either a collimated wavefront or a converting wavefront. An example of a reflector suitable for use as main reflector **106** may include the geometrically-flat electrically-parabolic surface reflector antenna disclosed in U.S. Pat. No. 4,905,014, although other reflective elements may also be suitable.

In some embodiments, main reflector **106** may be coupled by a hinge to the weapon **100** to allow main reflector **106** to fold back when the non-lethal portion is not being used. In some embodiments, main reflector **106** is foldable and may fold into two or more flat sections. One of the sections may be coupled by a hinge to weapon **100**, and the two or more flat sections may fold up at least partially around the weapon.

In some other embodiments, main reflector **106** comprises a single flat panel and is detachable from weapon **100**. In these embodiments, main reflector **106** may be stored in a user's backpack, for example, although the scope of the invention is not limited in this respect. In some embodiments, main reflector **106** may be able to be snapped-on to weapon **100**.

FIGS. **3**A-**3**F illustrate embodiments of the present invention having a foldable main reflector in which main reflector **106** folds up and wraps around the body of weapon **100** when the non-lethal portion is not in use. FIG. **3**A is a side view illustrating main reflector **106** in a fully folded-up position in accordance with some embodiments of the present invention. FIG. **3**B is a perspective view illustrating main reflector **106** in a fully folded-up position in accordance with some embodiments of the present invention. FIG. **3**C is a perspective view illustrating main reflector **106** in a partially folded-up position in accordance with some embodiments of the present invention. FIG. **3**D is a perspective view illustrating wings of main reflector **106** folded-up in accordance with some embodiments of the present invention. FIG. **3**E is a side view illustrating wings of main reflector **106** partially folded-up in accordance with some embodiments of the present invention. FIG. **3**F is a perspective view illustrating wings of main reflector **106** partially folded-up in accordance with some embodiments of the present invention.

FIG. **4**A is a side view illustrating main reflector **106** in a fully-deployed position in accordance with some embodiments of the present invention. FIG. **4**B is a perspective view illustrating main reflector **106** in a fully-deployed position in accordance with some embodiments of the present invention. FIG. **4**C is a top view of the weapon illustrated in FIGS. **4**A and **4**B. In these embodiments, main reflector **106** may be coupled by a hinge to weapon **100** to allow main reflector **106** to fold back when the non-lethal portion is not being used. In these embodiments, main reflector **106** comprises a single flat panel and may be detachable from weapon **100**. In these embodiments, main reflector **106** may be stored in a user's backpack, for example, although the scope of the invention is not limited in this respect. In some embodiments, main reflector **106** may be able to be snapped-on to weapon **100**.

FIG. **5**A is a side view illustrating the operation of the non-lethal portion of the weapon in accordance with embodiments of the present invention. FIG. **5**B is a perspective view illustrating the operation of the non-lethal portion of the weapon in accordance with embodiments of the present invention. The non-lethal portion is illustrated generating wavefront **107** toward a target.

FIG. **6**A is a side view illustrating the removable energy-storage module **112** in accordance with embodiments of the present invention. FIG. **6**B is a perspective view illustrating the removable energy-storage module **112** in accordance with embodiments of the present invention.

FIG. **7**A is a perspective view of a solid-state non-lethal weapon **700** that may be similar in function and operation to the non-lethal portion **100** of the combined lethal and non-lethal weapon shown in FIG. **1**. Elements in FIG. **7** identified by reference designators may have the same function as elements identified by reference designators having the same two least-significant digits in FIG. **1**. The functional architecture of the non-lethal weapon **700** may be same as that of the non-lethal portion **200** of the combined weapon, as described in conjunction with FIG. **2**.

The non-lethal weapon **700** does not require the magazine or other components of the lethal portion of the combined weapon. Thus the non-lethal weapon **700** may include a removable energy-storage module **712** which is significantly larger and heavier than the removable energy-storage module **112** of the combined weapon. FIG. **7**B is a side view of the non-lethal weapon **700** showing the reflector in the fully folded-up position, as was previously described with respect to the combined lethal and non-lethal weapon **100**.

FIG. **8**A is a perspective view of another solid-state non-lethal weapon **800** that may be similar in function and operation to the non-lethal weapon **700**, except that an energy storage module **810** may be a separate unit connected to the non-lethal weapon **800** by an umbilical cable **820**. The energy storage module **810** may be suitable for carrying on a belt or as a backpack. The non-lethal weapon **800** may or may not be capable of accepting a removable energy storage unit such as energy storage unit **712**. FIG. **8**B is a side view of the non-lethal weapon **800** showing the reflector in the fully folded-up position, as was previously described with respect to the combined lethal and non-lethal weapon **100**.

Closing Comments

The foregoing is merely illustrative and not limiting, having been presented by way of example only. Although examples have been shown and described, it will be apparent to those having ordinary skill in the art that changes, modifications, and/or alterations may be made.

Although many of the examples presented herein involve specific combinations of method acts or system elements, it should be understood that those acts and those elements may be combined in other ways to accomplish the same objectives. With regard to flowcharts, additional and fewer steps may be taken, and the steps as shown may be combined or further refined to achieve the methods described herein. Acts, elements and features discussed only in connection with one embodiment are not intended to be excluded from a similar role in other embodiments.

For means-plus-function limitations recited in the claims, the means are not intended to be limited to the means disclosed herein for performing the recited function, but are

intended to cover in scope any means, known now or later developed, for performing the recited function.

As used herein, "plurality" means two or more.

As used herein, a "set" of items may include one or more of such items.

As used herein, whether in the written description or the claims, the terms "comprising", "including", "carrying", "having", "containing", "involving", and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases "consisting of" and "consisting essentially of" respectively, are closed or semi-closed transitional phrases with respect to claims.

Use of ordinal terms such as "first", "second", "third", etc., in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another or the temporal order in which acts of a method are performed, but are used merely as labels to distinguish one claim element having a certain name from another element having a same name (but for use of the ordinal term) to distinguish the claim elements.

As used herein, "and/or" means that the listed items are alternatives, but the alternatives also include any combination of the listed items.

The invention claimed is:

1. A non-lethal weapon comprising:
- a solid-state source to transmit a high-power millimeter-wave initial wavefront
- a main reflector
- a sub-reflector to reflect the initial wavefront to the main reflector
- wherein the main reflector is to direct the reflected wavefront in a bore-sighted direction toward a target,
- wherein the wavefront directed by the main reflector comprises W-band millimeter-wave frequency radiation selected to penetrate a shallow skin-depth of human skin allowing the radiation to heat a region of the skin that includes pain sensors, and
- wherein a power density at the target is selected to cause a non-lethal deterring effect on the target by inducing pain on the human skin.

2. The non-lethal weapon of claim **1**, wherein the sub-reflector has a millimeter-wave reflective surface comprising at least a portion of one of a substantially hyperboloid, ellipsoid or paraboloid surface.

3. A non-lethal weapon, comprising:
- a solid-state source to transmit a high-power millimeter-wave initial wavefront
- a main reflector
- a sub-reflector to reflect the initial wavefront to the main reflector
- wherein the main reflector
  - directs the reflected wavefront in a bore-sighted direction toward a target and
  - generates a converging wavefront to converge at or near the target, wherein a convergence distance is determined to provide a predetermined power density at or near a surface of the target
- a rangefinder to determine a distance to the target
- a focusing element to change the convergence distance based on the distance to the target determined by the rangefinder.

4. The non-lethal weapon of claim **3**, wherein the focusing element comprises a millimeter-wave radio frequency lens.

5. The non-lethal weapon of claim **3**, wherein the focusing element is the sub-reflector.

6. The non-lethal weapon of claim **3**, wherein the focusing element is the solid-state source.

7. The non-lethal weapon of claim **3**, further comprising a controller to change a focus of the focusing element in response to changes in the distance to the target, wherein the focusing element is to change the convergence distance to generate a predetermined power density at or near the target.

8. A non-lethal weapon, comprising:
- a solid-state source comprising a high-power millimeter-wave amplifier to transmit a high-power millimeter-wave initial wavefront
- a main reflector
- a sub-reflector to reflect the initial wavefront to the main reflector
- wherein the main reflector is to direct the reflected wavefront in a bore-sighted direction toward a target, and
- wherein the high-power millimeter-wave amplifier further comprises an array of semiconductor amplifiers, each semiconductor amplifier having an output coupled to corresponding antenna element of an array of antenna elements.

9. The non-lethal weapon of claim **8**, wherein the initial wavefront is spatially combined from wavefronts radiated by the array of antenna elements.

10. A non-lethal weapon, comprising:
- a solid-state source comprising a high-power millimeter-wave amplifier to transmit a high-power millimeter-wave initial wavefront
- a replaceable energy-storage module to provide electrical energy for the millimeter-wave amplifier
- a main reflector
- a sub-reflector to reflect the initial wavefront to the main reflector
- wherein the main reflector is to direct the reflected wavefront in a bore-sighted direction toward a target.

11. The non-lethal weapon of claim **10**, further comprising a cooling element to cool the millimeter-wave amplifier, wherein the cooling element includes a reservoir, wherein the reservoir is replaceable and is replaced as part of the replaceable energy-storage module.

12. A non-lethal weapon, comprising:
- a solid-state source to transmit a high-power millimeter-wave initial wavefront
- a main reflector
- a sub-reflector to reflect the initial wavefront to the main reflector
- wherein the main reflector is to direct the reflected wavefront in a bore-sighted direction toward a target, and
- wherein the main reflector is a geometrically-flat electrically-parabolic surface reflector antenna having a plurality of antenna elements to receive and retransmit an incident wavefront, the antenna elements having circumferentially varying sizes arranged circumferentially around a center of the main reflector to generate either a collimating or converging wavefront.

13. A portable solid state millimeter wave directed energy weapon, comprising
- solid state source to transmit a high-power millimeter-wave initial wavefront
- a main reflector
- a sub-reflector to reflect the initial wavefront to the main reflector
- a rangefinder to determine a distance to the target
- wherein
  - the main reflector is to direct the reflected wavefront in a bore-sighted direction toward a target
  - the reflected wavefront comprises W-band millimeter-wave frequency radiation selected to penetrate a shal-

low skin-depth of human skin allowing the radiation to heat a region of the skin that includes pain sensors

a power density at the target is selected to cause a deterring effect by inducing pain on the human skin

the selected power density of the directed wavefront at or near the target is generated based on the determined distance.

14. The portable solid state millimeter wave directed energy weapon of claim **13**, further comprising a focusing element to change a focus distance of the directed wavefront based on the distance to the target.

15. A portable, solid state millimeter wave directed energy weapon, comprising:

solid state source to transmit a high-power millimeter-wave initial wavefront

a main reflector

a sub-reflector to reflect the initial wavefront to the main reflector

a laser designator to visually designate a target

wherein

the main reflector is to direct the reflected wavefront in a direction bore-sighted with the laser designator

the reflected wavefront comprises W-band millimeter-wave frequency radiation selected to penetrate a shallow skin-depth of human skin allowing the radiation to heat a region of the skin that includes pain sensors

a power density at the target is selected to cause a deterring effect by inducing pain on the human skin.

16. A portable solid state millimeter wave directed energy weapon, comprising:

a solid state source comprising a high-power millimeter-wave amplifier to transmit a high-power millimeter-wave initial wavefront

a cooling element to cool the amplifier, wherein the cooling element includes a reservoir, wherein the reservoir is replaceable and is replaced as part of a replaceable energy-storage module

a main reflector

a sub-reflector to reflect the initial wavefront to the main reflector

wherein

the main reflector is to direct the reflected wavefront in a bore-sighted direction toward a target

the reflected wavefront comprises W-band millimeter-wave frequency radiation selected to penetrate a shallow skin-depth of human skin allowing the radiation to heat a region of the skin that includes pain sensors

a power density at the target is selected to cause a deterring effect by inducing pain on the human skin.

17. A portable solid state millimeter wave directed energy weapon, comprising:

a solid state source to transmit a high-power millimeter-wave initial wavefront

a main reflector

a sub-reflector to reflect the initial wavefront to the main reflector

wherein

the main reflector is a geometrically-flat electrically-parabolic surface reflector antenna having a plurality of antenna elements to receive and retransmit an incident wavefront, the antenna elements having circumferentially varying sizes arranged circumferentially around a center of the main reflector to generate either a collimating or converging wavefront

the main reflector is to direct the reflected wavefront in a bore-sighted direction toward a target

the reflected wavefront comprises W-band millimeter-wave frequency radiation selected to penetrate a shallow skin-depth of human skin allowing the radiation to heat a region of the skin that includes pain sensors

a power density at the target is selected to cause a deterring effect by inducing pain on the human skin.

18. The portable solid state millimeter wave directed energy weapon of claim **17**, wherein the main reflector is to generate a converting wavefront to converge at or near the target, wherein a convergence distance is determined to provide a predetermined power density at or near a surface of the target.

19. The portable solid state millimeter wave directed energy weapon of claim **18**, wherein the main reflector is selected from the group consisting of

a reflector foldable into two or more flat sections, wherein one of the sections is hinged, and wherein the two or more flat sections fold up at least partially around the weapon, and

a single flat panel reflector that is detachable from the weapon.

* * * * *